A Chronology of the Explosive Eruptions of Kilauea

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INTRODUCTION

THE EXPLOSIVE ERUPTIONS of Kilauea, both prehistoric and historic, have been much discussed in the literature on Hawaiian volcanoes. Some early general observations attributed all of the surface ash deposits to the known explosive eruption of 1790 (Dana, 1891: 42–45; Jaggar, 1921: 114–118); others recognized evidence of several different prehistoric explosions (Hitchcock, 1911: 166–169; Sidney Powers, 1916). Later studies, with better exposures in artificial cuts on the windward rim of the crater, demonstrated a number of long intervals of quiet between several eruptions (Finch, 1925; Stone, 1926). This paper adds another, still more detailed, chapter to the accumulated knowledge, but much remains to be learned and recorded before complete understanding of the explosive phases of the volcano is attained. Many of the thoughts expressed herein are the result of discussion and exchange of ideas in the field with many coworkers, whose contributions are gratefully accepted and acknowledged. T. A. Jaggar, R. H. Finch, E. G. Wingate, A. E. Jones, all formerly with the Hawaiian Volcano Observatory; J. E. Doerr, Jr., former naturalist, Hawaii National Park; H. S. Palmer of the University of Hawaii; C. K. Wentworth of the Honolulu Board of Water Supply; and G. A. Macdonald of the United States Geological Survey have all contributed to the accumulation and consideration of material which is presented in this paper.

The erratic original deposition of the pyroclastics of Kilauea, controlled by combinations of atmospheric elements and directed explosions, has been amply discussed by Wentworth (1938: chapter 3). Very few individual beds of material could be traced with assurance as horizon markers, even for the short distance around the circumference of the crater, because of this erratic deposition. Also, removal of material by wind and water erosion during and between eruptions has been tremendous. As a net result of these two factors, there is no cross section in the area which contains a complete representation of all the explosion deposits.

Successful analysis of the stratigraphy and chronology of these deposits thus depends as much on appraising an erosion surface in the section as upon correctly describing the beds of pyroclastic materials. In this study, great emphasis has been placed on recognition of characteristics which can be used to distinguish unconformities and erosion surfaces produced during time intervals of perhaps a few hours between explosions from those produced during time intervals measured in years or tens of years between eruptions. The following characteristics of the present desert surface have been used to identify similar long-exposed surfaces in cross sections of the deposits: surface oxidation, encrustation, desert varnish on fragments, concentration of coarser particles, thinly laminated dust deposits, and truncation of previously consolidated layers (Plate 1B and 1C). Humus and other remains of plant growth are self-evident where they exist.

On each of eight segments of the crater rim, a complete composite section of the pyroclastic deposits was built up by compilation from a number of cross sections which were sufficiently close together so that correlations between them could be made with confidence. Particular attention was paid to recording depositional

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TABLE 1. GENERALIZED SECTION OF PYROCLASTIC DEPOSITS, KILAUEA RIM.

≈≈≈ indicates humus layer.

ERUPTION	TYPE	MAXIMUM THICKNESS	LOCATION OF MAXIMUM THICKNESS	THICKNESS ON WINDWARD RIM	TYPE OF SURFACE ON WINDWARD RIM
1924	Phreatic	18 inches	S.W. Floor Kilauea	1 inch	Forest
1815 ca.	Magmatic	48 inches	S.W. Rim Kilauea	0	
≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈
1790 ca.	Phreatic	45 inches	West Rim Kilauea	3 inches	
18–K	Phreatic	20 inches	S.W. Rim Kilauea	7 inches	Exposed
17–K	Phreatic	40 inches	S.W. Rim Kilauea	16 inches	Exposed
≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈
16–K	Magmatic	21 inches	S.E. Rim Kilauea	6 inches	
≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈
15–K	Phreatic	36 inches	S.W. Rim Kilauea	3 inches	
14–K	Phreatic	24 inches	S.W. Rim Kilauea	0	Exposed
13–K	Magmatic	80 inches	S.E. Rim Kilauea	10 inches	Exposed
≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈
12–K	Phreatic	10 inches	North Rim Kilauea	10 inches	
11–K	Phreatic	7 inches	N.W. Rim Kilauea	5 inches	Exposed
10–K	Phreatic	12 inches	S.W. Rim Kilauea	2 inches	Exposed
≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈
5–K to 9–K	Magmatic	175 inches (about)	S.E. Rim Kilauea	25 inches	
≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈
3–K to 4–K	Magmatic	200 inches (about)	S.E. Rim Kilauea	30 inches	
≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈
2–K	Phreatic	11 inches	N.E. Rim Kilauea	11 inches	
1–K	Magmatic	12 inches	N.E. Rim Kilauea	12 inches	? ?
≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈	≈≈≈
	Lava Flows	400 feet	North Rim Kilauea		
5–U	Magmatic	8 inches	N.W. Wall Kilauea		
4–U	Magmatic	8 inches	N.W. Wall Kilauea		
3–U	Magmatic	8 inches	N.W. Wall Kilauea		
2–U	Magmatic	12 inches	N.W. Wall Kilauea		
1–U	Magmatic	18 inches	N.W. Wall Kilauea		

breaks, erosional breaks, and breaks representing exposure as a surface for an important time interval. The thickest "blanket" occurrence (contrasted to pocket accumulations) in each small area is stated as the thickness of individual layers in the composite section; likewise the greatest number of separate layers found in each small area is used to represent a given eruption series. Thus, the composite section cannot be duplicated in any single section in an area, but represents the maximum number and blanket thickness of recognizable layers in each area. Similarly, composite sections were compiled for areas away from the rim in each major direction.

Cross correlation of these composite sections, depending as much on correlations of time–interval patterns as on a few recognizable horizon layers, has yielded a composite stratigraphic column and chronologic sequence of explosive activity for Kilauea. This is summarized in Table 1; the details of the most critical sections and the writer's correlation between sections are presented in Table 2. Eruptions of the two separate series have been numbered serially, i.e., 1-U for the oldest Uwekahuna tuff eruption, and 1-K for the oldest Keanakakoi eruption.

An overestimate of the time represented by some of the erosion surfaces may have yielded too great a number of eruptions. On the other hand, eruptions of the magnitude of the 1924 explosions might easily have been omitted entirely because of failure to discover remnant patches of their deposits. On the present rim surface, diligent search will find only a few patches of 1924 ash remaining (Plate 1B and 1C). Comparable remnant patches, buried in the stratigraphic section, could easily be overlooked.

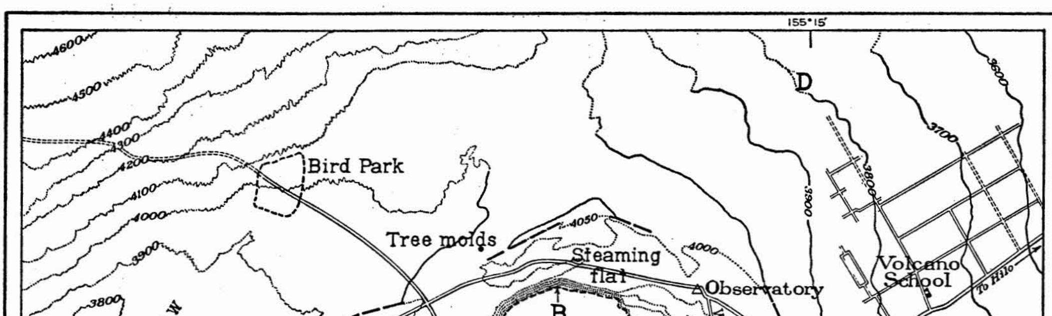

FIG. 1. Kilauea Crater and vicinity drawn from parts of the Glenwood and Kilauea Crater Quadrangles, U.S.G.S. topographic maps of Hawaii. Contour interval, 100 feet. Heavy contour lines are used on surfaces of the Kilauea dome which are apparently undisturbed by faulting; light lines are used for surfaces disturbed by faulting. Lettered localities are discussed in the text.

In the following text, it will be evident that descriptions of materials are presentations of fact, while appraisals of time intervals and cross correlations are presentations of the writer's interpretation.

UWEKAHUNA FORMATION

The oldest pyroclastic material which can be associated definitely with the central crater of Kilauea, the Uwekahuna formation (Stone, 1926: 27–28), is found in type locality in outcrops in the base of the northwest crater wall. The thickest section has been buried by the 1919 lava flow, but it was photographed by Jaggar in July, 1913 (Plate 2B), and cliff details in the photograph can be identified now in the field, making it possible to locate the exact position of the buried outcrop (locality A in Fig. 1 and Plate 2A) and to determine that the top of the tuff lies about 16 feet below the present surface of the 1919 pahoehoe lava at an estimated altitude of about 3,630 feet. This deposit was described by Sidney Powers (1916: 230) as "...exposed to a thickness of only 17 feet and for a length of about 500 feet, at the base of a cliff 170 feet in height." The present top of the cliff, above this deposit of

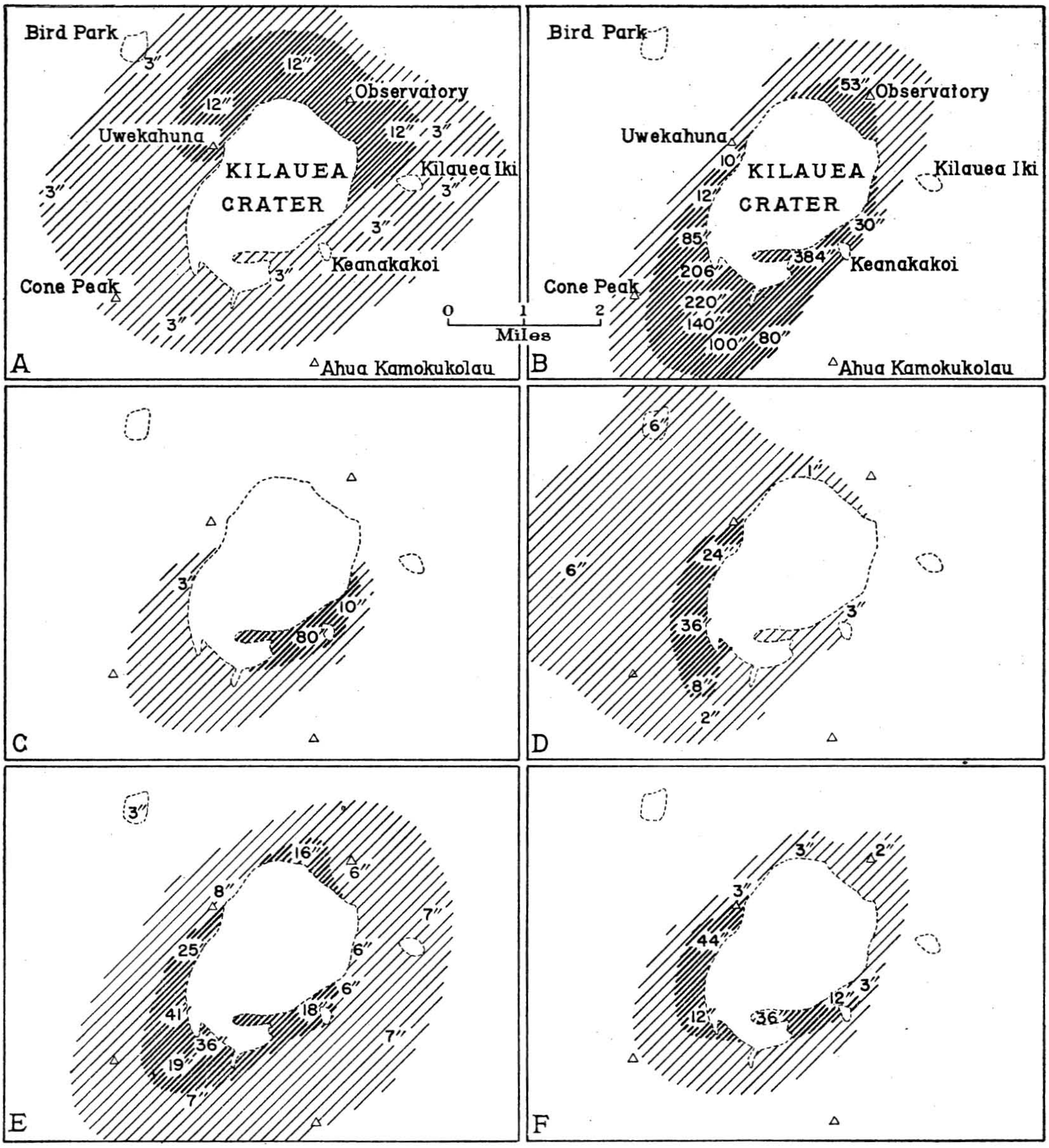

FIG. 2. Generalized pattern of distribution of several eruption deposits, shown at one-half the scale used in Figure 1. A, reticulite from eruption 1-K; B, composite vitric deposits from eruptions 3-K to 9-K, inclusive; C, vitric deposits from eruption 13-K; D, lithic deposits from eruption 15-K; E, lithic deposits from eruption 17-K; F, lithic deposits from the 1790 eruption.

Uwekahuna tuff, has an altitude of about 3,920 feet, indicating that the tuff lies beneath nearly 300 feet of bedded lava flows in the wall of the present crater, rather than the 170 feet suggested by Powers' sentence.

The most extensive occurrence of the Uwekahuna tuff is an apparently continuous, nearly horizontal deposit extending for about 5,000 feet (between localities B and C in Fig. 1 and Plate 3A), interbedded in the lavas of the northwest wall of Kilauea crater, and exposed in outcrops between talus fans at the base of the cliff. At B the tuff is 3 feet thick, lies 10 feet above the present crater floor at an altitude of 3,560 feet, and ends abruptly to the northeast against the edge of a rim block which has slumped about 20 feet with respect to the rim section in which the tuff is exposed—enough displacement to bury the tuff layer beneath the crater floor if it continues into the slumped block. At C the tuff is exposed at the base of the crater wall at an altitude of 3,590 feet, then follows an unconformity which truncates some lava layers in the cliff, rising steeply to the southwest to an altitude of about 3,690 feet where it levels off for a short distance before it disappears to the southwest behind a rim block which has slumped about 300 feet with respect to the main crater wall containing the tuff outcrops (Plates 2A and 3A).

A third occurrence of tuff, interbedded in lavas of crater-rim age, is found at the bottom of the largest tree mold under the surface pahoehoe flow a third of a mile northwest of that corner of Kilauea crater (Doerr, 1933: 3–7). Here, a group of koa trees apparently grew in soil formed on a surface blanket of tuff. At least 20 of these trees were surrounded, without being toppled over, by the last lava flood which covered this part of the outer slope of Kilauea, and molds of their trunks are preserved in the congealed lava. The largest mold, having a maximum diameter of 7 feet and a depth of about 18 feet, is so located that it acts as a sump to drain the surface runoff from several acres, and erosion by water entering the mold has removed the tuff layer to form a cavern as much as 20 feet wide and 150 feet long, floored by an underlying pahoehoe lava surface and roofed by the bottom of the upper lava flow. The tuff exposed along the sides of the cavern ranges from 0 to 36 inches in thickness. It mantled the irregular surface of the underlying pahoehoe lava, and had been greatly eroded before burial by the surface flow. The tuff lies at an altitude of slightly over 4,000 feet. For reasons stated in the following paragraphs, this tuff is correlated with the Uwekahuna formation of the type locality.

The type deposit of the Uwekahuna tuff (in the base of the northwest crater wall) ranges in thickness from a few inches to over 7 feet. It consists of several beds of fine to coarse vitric pumice, intercalated with variable thicknesses of lithic debris mantling an unmodified surface of pahoehoe lava. A typical section (locality S on Plates 2A and 2C) is:

	Inches
Bottom of overlying lava	
Coarse vitric pumice	3
Oxidized desert surface	
Coarse pumice with a few lithic fragments	6
Oxidized desert surface	
Agglomerate of lithic dust and fragments	15
Oxidized desert surface	
Coarse pumice with a few lithic fragments	4
Oxidized desert surface	
Coarse vitric pumice	8
Oxidized desert surface	
Fine vitric shards grading down to coarser	12
Surface of underlying lava flow	

Most outcrops show the five layers of vitric material separated by oxidized desert surfaces; the amount, coarseness, and texture of the intercalated lithic debris vary greatly from outcrop to outcrop. The section on the outer slope of the Kilauea dome at the bottom of the tree mold consists of:

	Inches
Bottom of overlying lava flow	
Vitric pumice	2
Oxidized surface	
Medium vitric pumice	5
Oxidized surface	
Fine to medium, bedded vitric pumice	6
Oxidized surface	
Fine, bedded vitric pumice	9
Oxidized surface	
Very fine vitric ash and pumice	3
Surface of underlying lava flow	

Thus, five epochs of magmatic fountaining, separated by times of quiet but with no intervening deposition of lithic debris, are represented at the tree mold locality. If the variable lenses of intercalated lithic debris are ignored in the type section, the five vitric layers in the

TABLE 2. CORRELATION OF COMPOSITE SECTIONS

The terms "dust," "sand," "gravel," and "rubble" refer to beds of crystal and lithic fragments, graded somewhat as to size of particle; the terms "ash," "shard," and "pumice" refer to beds of primary vitric fragments, graded similarly as to size. "Piso" denotes pisolitic structure of the fine materials, "agg" refers to an unsorted aggregate of lithic fragments ranging from dust to large blocks, and "pum agg" refers to rare beds of vitric lapilli which contain a few lithic blocks. Breaks between layers are represented by symbol lines as follows: breaks in deposition ''''''''''; desert surface ∿∿∿∿; humus or soil surface ≡≡≡.

ERUPTION	S.E. RIM 3,775	N.E. RIM 4,000	N. RIM 3,950	N.W. RIM 4,075	W. RIM 3,900	S.W. RIM 3,750	S. RIM 3,650
19-K 1790 Phreatic	3 in. Gravel	2 in. Gravel	3 in. Gravel	3 in. Gravel	2 in. Piso Dust 4 in. Sand 18 in. Gravel 12 in. Dust on Gravel 8 in. Sand on Gravel	12 in. Gravel	12 in. Gravel
18-K Phreatic	4 in. Piso Agg 3 in. Sand	2 in. Piso Agg	2 in. Piso Agg 1 in. Piso Agg 2 in. Dust on Sand	2 in. Piso Agg 3 in. Sand 2 in. 4 prs. Dust on Sand	4 in. Gravel 3 in. Dust on Gravel	4 in. Piso Agg 2 in. Sand 4 in. Sand 10 in. 4 prs. Dust on Sand	6 in. Piso Agg 6 in. Sand 1 in. Piso Dust 1 in. Piso Dust
17-K Phreatic	6 in. Sand-Gravel	3 in. 4 prs. Sand-Gravel 3 in. Sand-Gravel	1 in. Dust 9 in. 4 prs. Sand-Gravel 6 in. Gravel	1 in. Dust 1 in. Sand 2 in. Sand 4 in. Gravel	1 in. Dust 6 in. Sand-Gravel 6 in. Sand-Gravel 12 in. Gravel	4 in. Piso Dust 6 in. Sand-Gravel 15 in. 4 prs. Sand on Gravel 16 in. Piso Dust on Rubble	16 in. Bedded Sand-Gravel 2 in. Piso Agg
16-K Magmatic	1 in. Shard 2 in. Pum Agg 1 in. Shard	Pumice	1 in. Pumice	Pumice	Pumice	4 in. Piso Ash	3 in. Shard 18 in. Pum Agg
15-K Phreatic	3 in. Gravel		1 in. Piso Dust	24 in. Piso Dust-Rubble Agg	12 in. Piso Dust	36 in. Piso Dust-Rubble Agg	Remnant Blocks
14-K Phreatic				4 in. Sand	2 in. Piso Dust 7 in. Dust-Sand	12 in. Dust-Gravel 12 in. Dust-Gravel	
13-K Magmatic	5 in. Pum Agg 2 in. Piso Ash 1 in. Piso Ash 2 in. Piso Ash			1 in. Pumice	3 in. Piso Ash	2 in. Pumice	4 in. Ash 24 in. Pum Agg 23 in. Piso Ash and Pumice 18 in. Piso Ash 11 in. Shard
12-K Phreatic	9 in. Piso Dust on Sand	9 in. Sand	10 in. Dust-Sand	3 in. Dust-Gravel	2 in. Dust-Sand	2 in. Dust-Sand	8 in. Sand-Gravel
11-K Phreatic	1 in. Dust 3 in. Piso Dust 1 in. Sand	2 in. Dust-Sand 1 in. Piso Dust	2 in. Sand 2 in. Piso Dust 1 in. Sand	3 in. Piso Dust 4 in. Sand-Gravel			2 in. Dust 5 in. Piso Dust 1 in. Sand
10-K Phreatic	1 in. Piso Dust	2 in. Piso Dust	2 in. Piso Dust	3 in. Sand-Gravel		12 in. Dust on Sand-Gravel	3 in. Piso Dust
9-K Magmatic	Lava Flow	2 in. Pumice	4 in. Pumice	Few relics of Ash-Shard	42 in. Bedded Ash-Shard	36 in. Ash-Shard	12 in. Pumice
8-K Magmatic	20 in. Bedded Ash and Pumice	5 in. Pumice	2 in. Pumice			46 in. Piso Ash and Pumice	372 in. Bedded Shard and Pumice
7-K Magmatic		1 in. Shard				13 in. Shard	
6-K Magmatic		5 in. Shard				9 in. Pumice	
5-K Magmatic		10 in. Shard				32 in. Shard	
4-K Magmatic	10 in. Ash-Pumice	5 in. Ash-Pumice	12 in. Ash-Pumice			38 in. Shard	
3-K Magmatic		25 in. Ash-Pumice				32 in. Ash	
2-K Phreatic	1 in. Piso Dust	3 in. Dust-Sand 2 in. Piso Dust	6 in. Dust-Sand 5 in. Piso Dust				
1-K Magmatic	Reticulite	12 in. Reticulite	12 in. Reticulite	Reticulite	Reticulite	Reticulite	Reticulite
Lava Flows	Lava	Lava	Lava	Lava	400 ft. Lavas	Lava	Lava
5-U Magmatic					8 in. Pumice		
4-U Magmatic					4 in. Gravel 8 in. Pumice		
3-U Magmatic					12 in. Gravel 8 in. Pum-Agg		
2-U Magmatic					24 in. Rubble 12 in. Pumice		
1-U Magmatic					18 in. Ash-Shard Pahoehoe Lava		

12-K Phreatic	9 in. Piso Dust on Sand	9 in. Sand	10 in. Dust-Sand	5 in. Dust-Gravel	2 in. Dust-Sand	2 in. Dust-Sand	6 in. Sand-Gravel
11-K Phreatic	1 in. Dust 3 in. Piso Dust 1 in. Sand	2 in. Dust-Sand 1 in. Piso Dust	2 in. Sand 2 in. Piso Dust 1 in. Sand	3 in. Piso Dust 4 in. Sand-Gravel			2 in. Dust 5 in. Piso Dust 1 in. Sand
10-K Phreatic	1 in. Piso Dust	2 in. Piso Dust	2 in. Piso Dust	3 in. Sand-Gravel		12 in. Dust on Sand-Gravel	3 in. Piso Dust
9-K Magmatic	Lava Flow	2 in. Pumice	4 in. Pumice	Few relics of Ash-Shard	42 in. Bedded Ash-Shard	36 in. Ash-Shard	12 in. Pumice
8-K Magmatic	20 in. Bedded Ash and Pumice	5 in. Pumice	2 in. Pumice			46 in. Piso Ash and Pumice	372 in. Bedded Shard and Pumice
7-K Magmatic		1 in. Shard				13 in. Shard	
6-K Magmatic		5 in. Shard				9 in. Pumice	
5-K Magmatic		10 in. Shard				32 in. Shard	
4-K Magmatic	10 in. Ash-Pumice	5 in. Ash-Pumice	12 in. Ash-Pumice			38 in. Shard	
3-K Magmatic		25 in. Ash-Pumice				32 in. Ash	
2-K Phreatic	1 in. Piso Dust	3 in. Dust-Sand 2 in. Piso Dust	6 in. Dust-Sand 5 in. Piso Dust				
1-K Magmatic	Reticulite	12 in. Reticulite	12 in. Reticulite	Reticulite	Reticulite	Reticulite	Reticulite
Lava Flows	Lava	Lava	Lava	Lava	400 ft. Lavas	Lava	Lava
5-U Magmatic					8 in. Pumice		
4-U Magmatic					4 in. Gravel 8 in. Pumice		
3-U Magmatic					12 in. Gravel 8 in. Pum-Agg		
2-U Magmatic					24 in. Rubble 12 in. Pumice		
1-U Magmatic					18 in. Ash-Shard Pahoehoe Lava		

type sections of the Uwekahuna tuff may be correlated satisfactorily with the five vitric layers found at the tree mold locality. Future study may indicate that the lithic debris represents deposits from phreatic eruptions; the present evidence suggests that the composition and distribution of the lithic lenses are too erratic even to represent phreatic eruption deposits. At present it is thought that they are talus debris and outwash material interbedded with the mantle deposits of pumice on the floor of an old crater near the base of an old crater wall.

Of the tuff pictured in Plate 2B, Sidney Powers (1916: 230) gives the following description: "The beds are composed principally of yellow ash with some rock-fragments 1–2 inches in diameter, lava droplets, thread-lace scoria, and a few bombs 6 inches in length." Wentworth (1938: 88) discounts the possible correlation of this tuff with the Pahala tuff. Macdonald thinks it may be a continuation of the tuff still exposed northeast of Uwekahuna and it is so considered by the writer.

To the northwest and the northeast, beyond the edge of Kilauea surface flows, a deposit of partly consolidated crystal-vitric tuff is found which possibly correlates in age with one of these Uwekahuna magmatic eruptions. In the Bird Park area (Fig. 1), this bed lies on palagonitized Pahala tuff under the edge of an aa flow from Mauna Loa, which in turn is older than the lowest member of the Kilauea surface-ash deposits. About two miles northeast of Kilauea, at about 3,800 feet (locality D, Fig. 1), a bed of coarse, slightly palagonitized vitric shards lies on top of the completely palagonitized Glenwood tuff under a layer of unaltered surface ash from Kilauea.

All of these tuff deposits are considered parts of the same formation—the Uwekahuna tuff—deposited on different parts of an older Kilauean dome with a collapse caldera in the summit. The tuff is considered to be the remnant deposits of five epochs of intense lava fountaining or magmatic explosion separated by intervals of relative quiet measured in at least tens of years.

Studies now in progress on the rate of reforestation in given climatic zones may eventually yield data making useful the state of reforestation as a quantitative indicator of elapsed time since a given area was a new volcanic surface. At present, the use of forest growth as an indicator of the age of a surface is not much better than intelligent guessing, but one is tempted to use it in evaluating the lapse of time between the eruption of the pre-Uwekahuna-tuff pahoehoe flow and the destruction of the koa grove by the post-tuff flow at the tree mold locality. Present climatic conditions between the tree mold locality and an area just northeast of Keanakakoi are not widely different; the average annual rainfall is approximately 60 to 70 inches at both places, with slightly more fog at the tree mold area. Deposits from the 1790 eruption average over a foot thick on the Kilauea rim just north of Keanakakoi, but thin to 3 inches in less than a quarter of a mile to the northeast. The present surface is practically barren of tree growth north of Keanakakoi, but supports a dense forest of ohia and amaumau fern a quarter of a mile to the northeast. In fact, the transition from dense growth to barren surface occurs in a zone about 300 yards wide in which scattered trees and ferns have obtained a foothold (Plate 1A). The conclusion seems justified that the 1790 deposit killed the surface vegetation up to a fairly sharp line and that the advance of reforestation over the new surface has progressed about 300 yards in 150 years. Judging from the present relationship of the slopes of Kilauea to the forested slopes of Mauna Loa, the tree mold area could not have been closer than half a mile (probably a mile) to living koa forest after the eruption of the pre-Uwekahuna surface lava flow. The trees which formed the molds hardly could have obtained foothold until the end of the second Uwekahuna magmatic explosion since its eruption of 9 inches of pumice at this spot probably would have killed forest growth. The advance of the koa forest across more than half a mile of barren surface would seem to demand at least 300 years, and growth of the tree with a diameter of 7 feet would seem to require perhaps 300 years. The time lapse between emplacement of the two upper lava flows enclosing the Uwekahuna tuff could well approach 1,000 years.

Above the lower outcrops of Uwekahuna tuff, truncated by the present crater wall, are at least 30 pahoehoe flows ranging in thickness from 1 to 35 feet (Macdonald, in press) and separated by flow contacts which show no evidence of prolonged erosion or soil accumulation. This epoch of rapidly recurring eruptions of fluid lava apparently filled the supposed old crater, overflowed the old outer rim at least one flow deep on the northwest (the tree mold flow), and restored a constructional dome shape to the summit of Kilauea. Reconstruction of the probable shape of the dome by using present surface contours in segments that have not been faulted, and restoring the measurable amount of slump in the down-faulted segments, indicates that the probable summit of the dome was elongated east–west across the north end of the present caldera between Uwekahuna and the east end of Kilauea Iki. On Figure 1, the contours of the unfaulted Kilauea surface are indicated by a slightly heavier contour line.

This epoch of rapidly recurring overflow apparently closed with the collapse of at least part of the present caldera and with the start of a series of explosive eruptions which deposited the members of the Keanakakoi formation (Wentworth, 1938: 92) on the surface of the present caldera rim.

KEANAKAKOI FORMATION

The Keanakakoi formation includes all fragmental deposits emplaced on the present rim of Kilauea by explosive eruption of the summit crater. In theory it should represent all of the late explosive eruptions, but of necessity any explosions too feeble to deposit an appreciable layer of material on the rim exclude themselves because they have left no visible record. The present interpretation identifies deposits from 21 different explosive eruptions separated by breaks representing time lapses to be measured at least in years. Not less than seven of these breaks were long enough for re-establishment of a vegetative cover on the humid windward rim. Ten of the eruptions involved only phreatic explosions; 11 were magmatic explosions or intense lava fountaining.

The oldest layer of known pyroclastic material on the surface of the Kilauea rim lavas is the "reticulite" (Wentworth, 1938: 93) or "thread-lace scoria" (Dana, 1891: 163). In places on the northeast rim, thin patches of lavender clay are found on the lava under the reticulite, but it is not known whether this clay represents the remnants of an earlier explosive eruption deposit, or is merely surface detritus which was mechanically eroded from the surface of bare pahoehoe, concentrated into pockets, and mixed with accumulated humus. Oxidation of the glassy pahoehoe skin is found everywhere, though it cannot be demonstrated that this oxidation occurred before deposition of the reticulite. The surface of the clay pockets is also oxidized and contains humus, so it is quite probable that a vegetative cover had at least partially developed on the northeast rim prior to the eruption of the reticulite. This deposit can be found in blanket thicknesses of about 12 inches on the north and east rims of the crater (Fig. 2A). Thin blanket deposits and pocket accumulations have been found entirely around the rim and as far away as the Bird Park. It is found under the edge of the Keamoku aa flow from Mauna Loa.

It is difficult to appraise the time interval between deposition of the reticulite and its burial by the next eruption deposit. Charcoal fragments are found on the surface of the reticulite on the northeast rim. They may be relics of vegetation burned by the deposition of the reticulite, or they may represent vegetation that grew on the surface of the reticulite. The reticulite is a material which could support vegetative growth and show very little decomposition or mixture with humus.

The second eruption was phreatic, and deposits from it are found only on the north and east rims. On the slumped rim-blocks below Waldron's Ledge along the Volcano House–Halemaumau Trail, are 36 inches of mixed, tan pisolitic clay and lithic fragments up to a cubic foot in volume. The deposit on Byron's Ledge, at the north end, is similar in make-up, but only 6 inches thick. On the Steaming Flat (N. Rim 3,950 in Table 2), the deposit consists of 5 inches of pisolitic tan clay overlain by 6 inches of layered dust and fine sand. This 11-inch blanket on the Steaming Flat probably would have destroyed existing vegetation. A humus layer on its top indicates that some soil was formed and a vegetative cover developed again before the next eruption. Scattered pumice is mixed in with the soil surface in many places, and a thin pahoehoe lava flow covered part of the north end of Byron's Ledge during this time interval.

Remnant deposits from the third and fourth explosive eruptions range in thickness from about 200 inches west of Keanakakoi (S. Rim 3,650 in Table 2) to 2 inches on the top of Uwekahuna Bluff (N.W. Rim 4,075 in Table 2). A 12-inch section on the Steaming Bluff consists of:

	Inches
Humus layer at old surface	
Fine vitric shards	2
Wind-blown vitric shards, dune-like	1
Fine vitric shards grading down to pumice	2
Depositional break	
Pea-size vitric lapilli	2
Depositional break	
Fine vitric shards grading down to pumice	2
Depositional break	
Fine vitric shards grading down to coarse pumice	3
Humus layer, surface of second eruption deposit	

The thickest section of these vitric deposits (near Keanakakoi) is in a cliff which is inaccessible for detailed study. In the walls of a gaping surface crack southeast of Cone Peak, under the crack flow, the section is 108 inches of alternating beds of fine, dun-colored pisolitic vitric shards and coarser pumice lapilli up to one-half inch in diameter. One mile east (locality E in Fig. 1), the section consists of about 80 inches of bedded, dun-colored vitric shards; another half a mile to the east, just northwest of Ahua Kamokukolau, the section is only 6 inches of unconsolidated, apparently wind-drifted, dun-colored vitric shards.

Following the deposition of these vitric beds in the third and fourth eruptions, a complete vegetative cover became re-established on the windward rim, and pronounced erosion occurred on the leeward rim (Plates 1D and 4B).

A series of at least five magmatic explosive eruptions next deposited beds of vitric shards and pumice totaling over 20 inches on the windward rim and over 130 inches on the leeward rim. A thin pahoehoe flow lies on top of this series on the southeast rim of Kilauea near Keanakakoi. The eruptions were separated by time intervals long enough to produce exposed surface features but too short to permit the growth of vegetative cover on the windward rim; however, recovery of the windward rim vegetation followed the last of these eruptions.

The small size and fragmental shapes of the shards making up a large part of these thick vitric beds and the presence of pisolitic structures, seem to indicate that the eruptions which produced them were more violently explosive than the lava fountains which have been observed at Kilauea (or Mauna Loa) in recent years. On the other hand, the explosions were less violent than some of the phreatic blasts which lifted fine material into the upper air above the trade winds, because the distribution of the vitric beds (Fig. 2B) is typical of deposition under trade-wind influence.

The extremely rapid thinning of these beds of vitric ash in all directions is very striking. Beds 100 inches in thickness half a mile due southwest from the present leeward rim of the crater decrease to less than 10 inches in the next half mile to leeward. The size of particles decreases rapidly also; no particles reaching a diameter of ½ inch are found in the beds of the original blanket deposit at distances 2 miles to leeward. Pieces of frothy pumice considerably larger than this are found in pockets as much as 4 miles distant, but their occurrence indicates, without much question, that they have been skipped and rolled downhill by wind drifting. This very localized distribution of the products of the greatest vitric ash eruptions known to have come from the central crater of Kilauea, raises a serious question as to the ability of earlier Kilauea crater explosions to have contributed directly and appreciably to the ash deposits of Hilina Pali and similar areas over 10 miles from the central crater.

The next three eruptions, numbers 10, 11, and 12, were relatively weak phreatic explosions, as the lithic particles in their deposits are all smaller than medium gravel. The earlier deposit is thicker on the southwest rim, perhaps due to trade-wind control during deposition, while the latter two are thickest on the windward rim. The time intervening between each of these eruptions was insufficient for reforestation, but the time following the third one was long enough to produce a vegetative cover, as evidenced in the section on the southeast rim at the edge of the humid area. A good soil is present on the deposit from this twelfth eruption on the northwest rim, but it represents a telescoping of several ensuing time intervals and uninterrupted growth of vegetation up to the time of the seventeenth eruption.

The thirteenth eruption was essentially one of intense fountaining, but locally several of the explosions hurled out small amounts of wall-rock fragments (probably from talus piles within the craters) which are mingled with the pumice. The deposit is localized (Fig. 2C): 80 inches of coarse and fine pumice with a few lithic blocks are found on the south rim due west of Keanakakoi; 11 inches of bedded pumice with a few small lithic fragments are found on the southeast rim; and a few inches of pumice alone are found on the rest of the circumference of the crater. A thin pahoehoe flow, which issued from a concentric crack a mile southwest of the crater and flowed over several acres of surface, is correlated tentatively with this magmatic eruption.

In detail, the thickest section of this deposit consists of:

	Inches
Desert surface	
Fine vitric shards approaching dune sand	4
Textural break	
Bedded, fine to coarse pumice, some lithic fragments	24
Textural break	
Bedded, pisolitic vitric shards and coarse pumice	40
Textural break	
Coarse pumice	12
Surface of underlying material	

The fourteenth eruption was phreatic, and its deposits remain only on the west and southwest rim of the crater: 3 inches of lithic fragments up to half an inch in diameter on the west rim, and 24 inches of bedded lithic dust on medium to coarse lithic fragments on the southwest rim.

The fifteenth eruption was a phreatic explosion which deposited lithic blocks of over a cubic foot in volume more than a quarter of a mile beyond the present southwest rim and on Uwekahuna Bluff (Fig. 2D). At the southwest rim, the deposit is 36 inches thick and consists of large to small lithic blocks mixed through a matrix of pisolitic dust. Away from the crater rim, the lithic fragments play out rapidly from the thick layer of partly consolidated, fine pisolitic dust. At the contact of the Kilauea slope against Mauna Loa at the foot of Kipuka Puaulu (Bird Park), the section is over 6 inches thick, consisting of an upper layer of compact pisolitic dust, a middle layer of dust and fine lithic sand, and a lower layer of pisolitic dust. This bed mantles the lower mile of the Mauna Loa slope northwest of Kilauea. It is 6 inches thick at B.M. 3,633 where the belt road climbs onto the edge of the Keamoku flow 2 miles west of the crater. At F in Figure 1, east of Cone Peak, the section shows oxidation of the upper members and consists of 4 inches of dust to fine sand, 1 inch of pisolitic dust, 2 inches of laminated dust on coarse sand, and 1 inch of medium-sized lithic sand.

The time intervening between the thirteenth and the sixteenth eruptions was long enough for a vegetative cover to develop on the southeast rim. The fact that oxidation is deeper (in the leeward sections) on the deposits of the fifteenth eruption than on either the thirteenth or fourteenth suggests that the greater part of the time interval occurred between the fifteenth and sixteenth eruptions.

The deposits of pumice, mixed with a few lithic fragments, of the sixteenth eruption are concentrated to thicknesses of 21 inches on the south rim near Keanakakoi. At the edge of the humid area (S.E. Rim 3,775 in Table 2) 4 inches of this pumice are topped with a good humus layer. Elsewhere the surface shows much erosion and oxidation of wind-blown surface material and carries abundant drift pumice and Pele's hair.

The remnant rim deposits of the seventeenth eruption range in thickness from 6 inches on the northeast rim to 41 inches on the southwest rim (Fig. 2E) and are sufficiently well preserved to suggest an appraisal of the explosive phases of the eruption. After an assumed preliminary stage which left no record on the rim, the first (recorded) phase was the most violent phreatic explosion of the eruption and was followed by a pause in which rains cleared the air of dust. This is suggested by the basal layer which is found as follows: 3 inches of lithic fragments ranging from coarse sand up to 3-inch diameter (a few blocks exceeding a cubic foot in volume) capped by a top film of fine sand and dust on the northeast rim; 24 inches of lithic fragments ranging from a quarter inch up to 6 inches (a few blocks of as much as 4 cubic feet in volume) capped by 1 inch of pisolitic dust on the southwest rim; and intermediate thicknesses of similar materials on the southeast and northwest rims. The second phase included at least four explosions following one another so closely that the air was not cleared of fine dust between them. The deposit on the northeast rim consists of four layers of coarse to fine lithic sand totaling about 3 inches, and on the southwest rim consists of four layers of lithic lapilli (up to ½ inch in diameter) grading into coarse lithic sand totaling about 15 inches in thickness. The third phase included one explosion followed by rains localized on the leeward side of the crater. This last explosion deposited a thin layer of lithic sand grading into about an inch of non-pisolitic dust on the windward rim and 6 inches of lithic lapilli and coarse lithic sand capped by 4 inches of pisolitic dust on the leeward rim.

No humus formed on these deposits on the windward rim, but the surface features indicate wind work, crustation, and oxidation characteristic of exposure for an interval at least of some years' duration. Pumice, Pele's hair, and Pele's tears scattered on the surface indicate lava fountaining during the interval.

The deposits from the eighteenth eruption range in thickness from 2 inches on the windward rim to 20 inches on the leeward rim. A possible separation of the explosions is again suggested by the details of the section on the southwest rim. At the start of the eruption, four relatively small phreatic explosions deposited a total of 10 inches on the southwest rim made up of four layers of coarse lithic sand, each capped by lithic dust, and a total of 2 inches of pisolitic lithic dust on the windward rim. Two more phreatic explosions deposited, respectively, a 4-inch and a 2-inch layer of coarse to fine lithic sand on the leeward rim and a 1-inch layer of pisolitic dust mixed with coarse lithic sand on the windward rim. Perhaps both of these phases occurred during tradewind rains. The last explosion deposited an unsorted aggregate of lithic fragments in a matrix of tan pisolitic dust all around the rim, ranging from 2 inches thick on the northeast to 12 inches on the south near Keanakakoi.

The surface of this deposit shows the effects of prolonged exposure and wind erosion (Plate 4C) in every area, but no humus layer accumulated on the windward rim.

The remnant deposits on the crater rim from the 1790 eruption (Finch, 1947: 1) range in thickness from about 3 inches on the windward rim to a maximum of about 44 inches on the broad fault block forming the inner, western rim of Kilauea (Fig. 2F). At this locality, the deposits indicate at least three main explosive phases. The lowest layer is 8 inches of lithic fragments (up to 2 inches in diameter) grading up into a thin layer of fine lithic sand. The middle layer is 12 inches of unsorted, fine to coarse, lithic fragments capped by a thin layer of lithic dust. The upper layer, 24 inches thick, consists of 18 inches of medium to large lithic blocks (up to 6 inches) grading up into 4 inches of coarse to fine lithic sand, grading into 2 inches of fine lithic dust. A mile south, on the southwest rim, the deposit is about 12 inches of unsorted, fine to coarse, lithic fragments, and it continues in similar thickness and composition around the south rim to the section due north of Keanakakoi. From this point northeast along the rim, the deposit thins very rapidly to 3 inches in less than a quarter of a mile (Plate 1A). On all of the windward rim, the deposit consists of unstratified material ranging from dust to pebbles approximating a hen's egg in size, now mixed with humus as well as some indistinguishable, fine material from historic eruptions. It makes up the bulk of the present surface soil, though there has been no chemical decomposition of the lithic fragments. On the leeward desert rim, except where it is covered by later deposits, coarse fragments from this deposit have been concentrated and fine material has been crusted to form the stony pavement characteristic of the desert surface.

The thickness of this deposit decreases rapidly in all directions away from the crater. A maximum thickness of 6 inches can be found on the outermost rim due west of Halemaumau at 3,800 feet altitude, on the broad slope east of Cone Peak at 3,600 feet, and due south of Keanakakoi at 3,600 feet. The size of fragments decreases and the proportion of dust increases with distance away from the crater rim. Many blocks with a volume exceeding a cubic foot and a few with a volume exceeding a cubic yard are found on the rim around the southwesterly half; fragments up to 6 inches in diameter are found to the southwest as far as Cone Peak; fragments up to 2 inches in diameter are not rare to the southwest as far as the 3,400-foot contour; and many fragments reach half an inch in diameter near Mauna Iki at 2,900 feet.

The deposit is made up almost entirely of crystalline fragments and contains no juvenile vitric pumice, though, in a small area, bread-crusted blocks and cored bombs are common. Near Keanakakoi, such fragments make up nearly 1 per cent of the deposit and blocks and cored bombs up to a cubic foot in volume are found as much as half a mile from the crater rim. They are very rare in the other quadrants of the crater rim. The insignificant amount of still-plastic material (at time of eruption) represented by these bombs is considered to have been "bench magma" left behind by the abrupt withdrawal of the active magma column, and the eruption is believed to have been made up entirely of phreatic explosions.

Correlation of specific eruption layers in sections somewhat distant from the rim of the crater is almost entirely speculative. On windward slopes an appreciable thickness of material was deposited by very few eruptions, and any thin deposits lost their identity by incorporation in the then-existing, surface soil. To leeward, immediate attack by wind erosion rapidly destroyed most thin layers of ash, adding the coarser materials to the moving sand dunes and transporting the fine material entirely out of the area in which it was deposited. Beds of water-saturated pisolitic mud which have been partly consolidated and surface-crusted during the initial drying out are the only thin leeward layers which remain in place for an appreciable length of time.

In the belt of young ohia forest a mile northeast of the rim of Kilauea, the ash section and a possible correlation with the Keanakakoi series eruptions is:

	Eruption
4 inches of surface humus grading into next layer	
2 inches of lithic sand and fine gravel	1790
3 inches of pisolitic aggregate	18-K
7 inches of lithic sand and gravel	17-K
Humus layer	
8 inches of lithic sand and gravel	12-K
Humus layer	
2 inches of pumice mixed with humus	9-K
8 inches of vitric ash mixed with humus	8-K to 3-K
Humus layer	
2 inches of fine clay	2-K
8 inches of reticulite	1-K

Two miles to the northeast, in a more mature forest made up of ohia, tree fern, and koa, the section is:

	Eruption
Humus top layer	
8 inches of lithic sand and fragments mixed with humus	1790 to 12-K
1 inch of pumice mixed with humus	9-K
15 inches of vitric shards and ash	8-K to 1-K

In the desert, 6 miles to the southwest of Kilauea, at the locality of the human footprints, there remain patches of two pisolitic layers, probably representing beds of original deposition, and much wind-transported, dune sand. One section showed:

	Inches
Shifting dune sand	6
Crusted stony pisolite layer	2
Imprisoned dune sand	36
Mud-cracked pisolitic layer	2
Imprisoned dune sand	48
Pahoehoe lava surface	

The lower pisolitic bed is made up of three layers: at the bottom is half an inch of finely laminated dust, next an inch of pisolitic dust, and on top is another half an inch of finely laminated dust (Plate 3B). The surface of this bed is cut by mud cracks which extend down part way into the pisolitic layer. The cracks have been filled with fine drifted dust. In the surface of the layer are found some of the fossil footprints, impressed even into the middle of the central pisolitic layer. The whole bed has been consolidated enough to resist immediate removal by wind and rain, but it has been and is being removed slowly by erosion. In many places all of the upper laminated dust and the middle pisolitic layers have been removed, leaving only a thin crust of the lower, laminated, dust layer. In the section described above, a trench was driven into the bank exposing a 10-foot section containing the two footprint-bearing pisolitic beds with dune sand between. In this 10-foot artificial exposure, the lower bed ranged in thickness from 2 inches to half an inch in places where wind scour had removed the upper two-thirds of the bed prior to its burial by the dune sand.

The upper footprint bed consists of mixed sand, lithic fragments (up to a half inch in diameter), and pisolitic dust and ranges in thickness from 1.5 to 2 inches. Its surface is protected by a thin crust, and the entire layer is partly consolidated. The scattered remnants of this deposit in the footprint area have not yet been traced with any assurance into the continuous layers nearer the crater which can be correlated with eruptions with some confidence. It appears reasonable to assign the upper, crusted footprint layer to the 1790 eruption, chiefly because it is the youngest and because it is associated with the known presence of Hawaiians in the area during the eruption. On the other hand, it might be argued that the two pisolitic layers should be correlated with the two phreatic eruptions which made the thickest deposits remnant on the southwest rim near the crater, namely the seventeenth and fifteenth eruptions. Possibly more detailed field work may yield data on which a definite correlation may be based. At present, it seems certain that the two footprint-bearing layers are products of two different phreatic eruptions which probably should be chosen from among the 1790, the seventeenth, and the fifteenth eruptions.

Evaluation of the time span covered by the eruptions of the Keanakakoi formation can be no better than a guess at present; but perhaps a guess, tempered by the impressions of relative time intervals and periods of exposure that one gets while "living with the problem" in the field, is worth recording.

The present forest cover on the northeast rim of Kilauea is probably the heaviest tree growth which has developed in any period since the emplacement of the upper lava flow of this part of the crater rim. The deposits of the 1790 and the eighteenth eruption on this part of the rim are too light to have killed well-established trees, though each probably killed small ground-covering vegetation. Deposits from the seventeenth eruption were thick enough probably to have killed all vegetation as far as half a mile to the northeast of the rim. Judging from comments of early visitors, a good ground cover and at least a scattered stand of scrubby ohia were established on the immediate rim as long ago as 1825. Taking everything into consideration, my impression is that the present reforestation of the rim since the seventeenth eruption has required approximately 400 years. The next heaviest vegetative cover formed on the northeast rim was established in the time interval between the twelfth and the seventeenth eruptions. The humus layer indicates heavy ground cover, and molds of small ohia trees have been found. The "kill" of the twelfth eruption probably extended about the same distance to the northeast of the rim as did that of the seventeenth. This time interval may have been about 300 years. Much less time seems to be required for the intervals between the ninth and the twelfth, and the fifth and the ninth eruptions, since the humus is thin. The vegetative cover developed on the deposits of the fourth eruption consisted largely of fern, ohelo, and other low growth and probably could have developed in about 200 years. A similar period apparently would suffice for the time between the second and third eruptions. An estimate of perhaps 1,500 years is suggested for the total time covering the explosive eruptions of the Keanakakoi formation.

CONCLUSIONS

Detailed study of the disconformities and unconformities between the beds in the pyroclastic deposits of Kilauea crater and appraisal of the relative time intervals which they represent, combined with study of the lithology of the beds, have facilitated a preliminary catalog-

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PLATE 1A. Abrupt transition from heavy forest cover to barren surface, possibly the southeast limit of "forest kill" by the 1790 eruption, perpetuated because local climatic conditions have inhibited reforestation. Looking northeast across Keanakakoi Crater (foreground) and the east end of Kilauea (left background) from locality P. Photograph by H. A. Powers, September, 1947.

PLATE 1B. Remnant of the mantle of 1924 bedded lithic ash, originally plus 5 inches thick, as exposed by the small excavation in the foreground. This area is subject to torrential rains, but the absence of an incised drainage net indicates that runoff erosion is subordinate in effectiveness to wind planation and undercutting. The present surface is planed across the bedding of 1924 ash at a low angle, and a desert pavement of residual larger fragments is beginning to accumulate. Photograph by H. A. Powers, September, 1947, at locality M.

PLATE 1C. Remnant of 1924 ash, originally plus 3 inches thick in this area, showing results of wind erosion by undercutting along least resistant layers. Most of the remaining patches of the 1924 ash mantle are in slight surface depressions where moisture persists longer than on the adjacent slopes, perhaps retarding removal of the patches by wind erosion. Photograph by H. A. Powers, September, 1947, at locality N.

PLATE 1D. Keanakakoi formation pyroclastics mantling the inner face of the southwest wall of Kilauea Crater exposed by a short inflowing ephemeral stream. The bedded vitric deposits of the third and fourth eruptions (lower left) are truncated by an erosion surface equivalent to a good humus layer on the humid northeast crater rim. On the unconformity are the bedded vitric deposits of the fifth to the ninth eruptions (center and right center). The upper beds represent the seventeenth to 1790 eruptions mantling a major erosion surface from which all deposits of the tenth to the sixteenth eruptions have been removed. Photograph by H. A. Powers, September, 1947, at locality T.

PLATE 1A

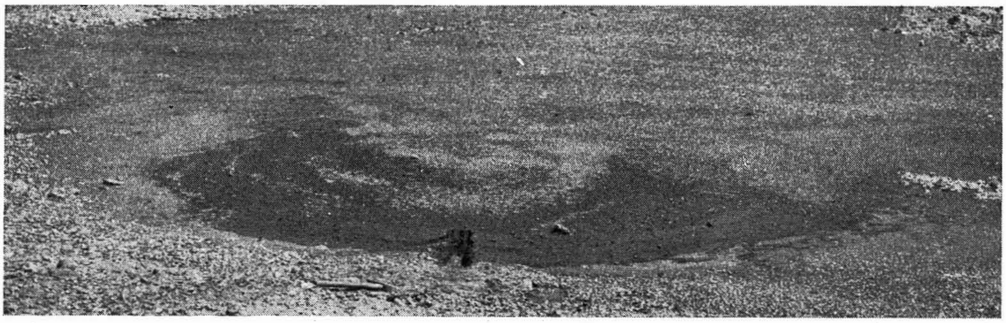

PLATE 1B

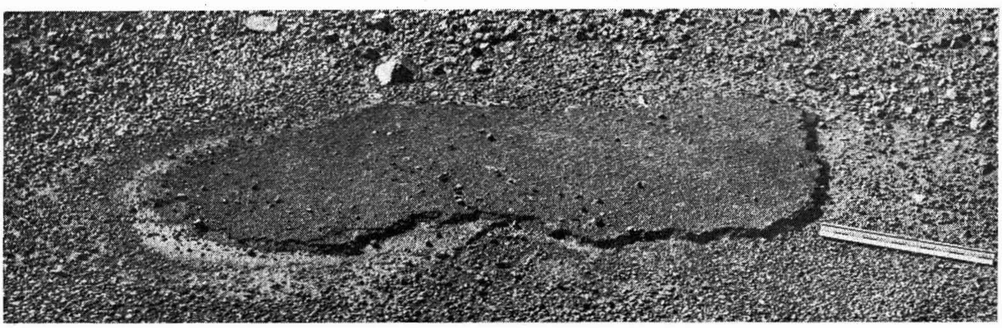

PLATE 1C

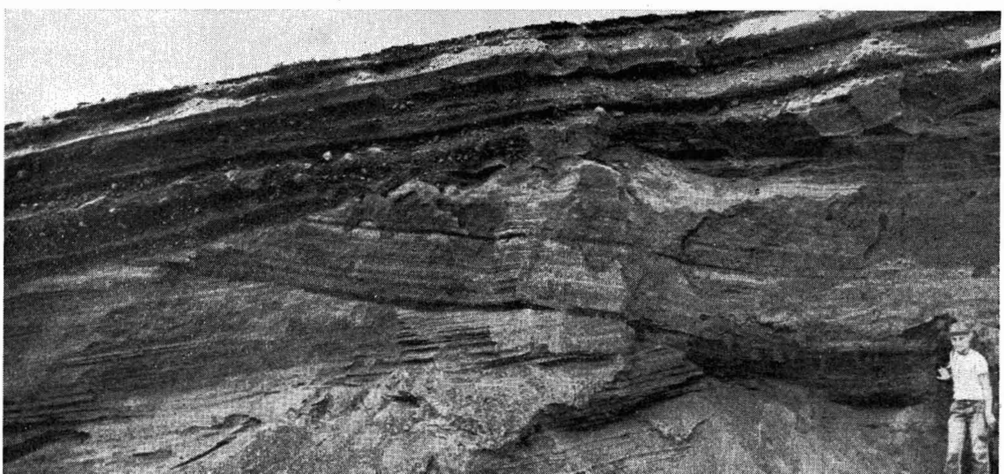

PLATE 1D

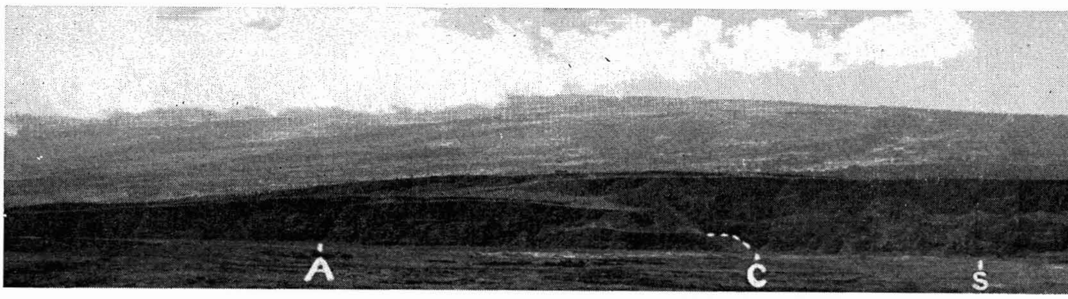

PLATE 2A. Northwest wall of Kilauea Crater seen from near Keanakakoi. The Uwekahuna tuff formerly was exposed at A, and at present is exposed at C and S. The rim block containing A has slumped a greater amount from its original elevation than has the rim block containing C and S. Photograph by H. A. Powers, September, 1947.

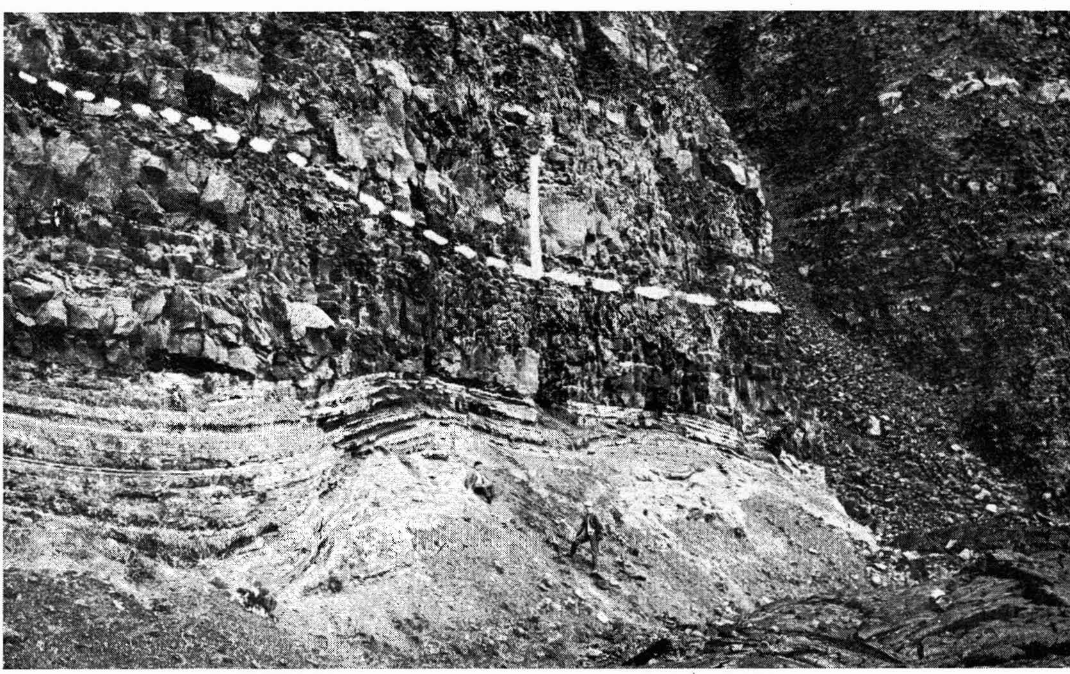

PLATE 2B. Bedded Uwekahuna tuff at locality A buried by the 1919 pahoehoe flow on the crater floor which filled against the cliff as high as the dashed line. Vertical solid line indicates the span of a 13-foot surveyor's rod located against points of the cliff face which have not changed since the photograph was taken by T. A. Jaggar, July, 1913.

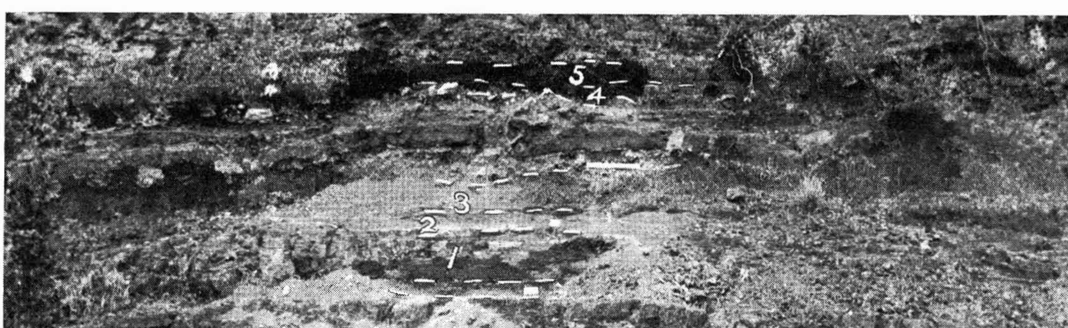

PLATE 2C. Uwekahuna tuff, 3½ feet deep, lying on the basal pahoehoe flow exposed in the cliff at S. Base of tuff is 5 feet above the present crater floor. Inter-eruption surfaces have been spotted on the negative. Photograph by H. A. Powers, September, 1947.

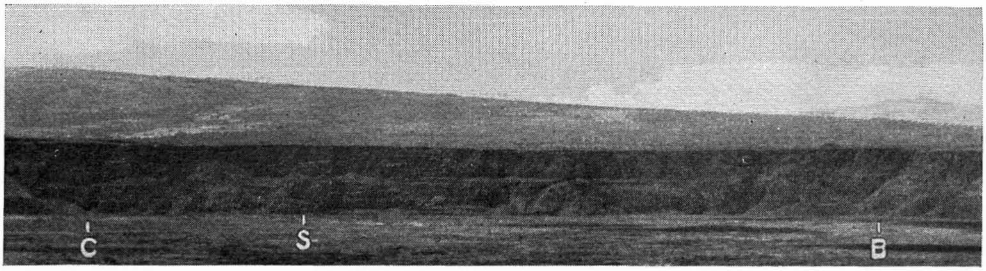

PLATE 3A. Kilauea, northwest crater wall, seen from Keanakakoi, in which Uwekahuna tuff crops out a few feet above the crater floor between talus fans from C to B. Photograph by H. A. Powers, September, 1947.

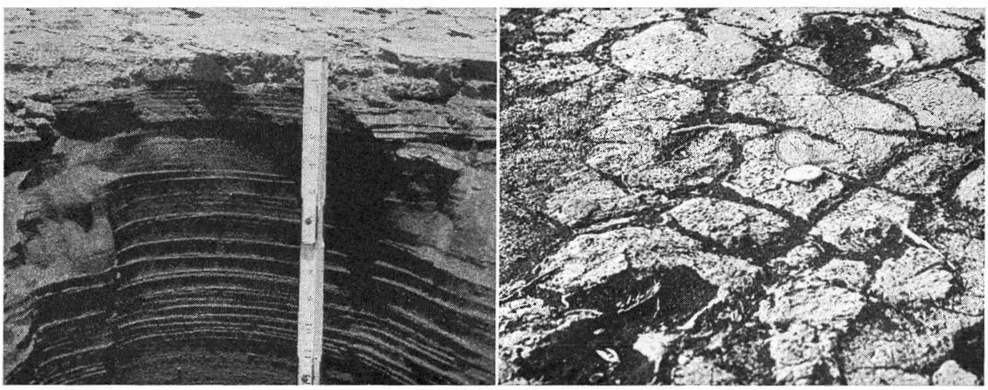

PLATE 3B. Lower mud-cracked stratum retaining human footprints, lying on bedded dune sand about 6 miles southwest of Kilauea. Photograph of footprints by T. A. Jaggar, July, 1921; of vertical section by H. A. Powers, August, 1931.

PLATE 3C. Upper crusted stratum of stony pisolite retaining human footprints in the same locality. Photograph by T. A. Jaggar, July, 1921.

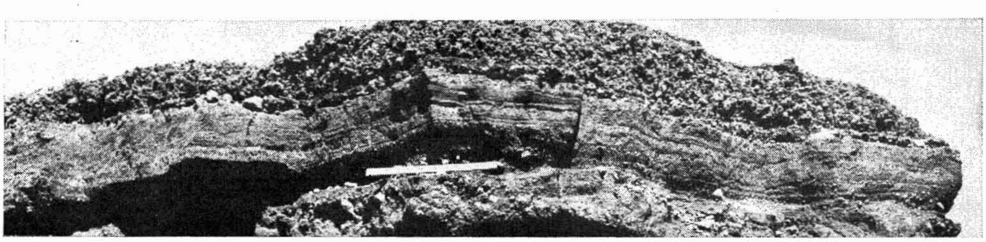

PLATE 3D. Pumice of about 1815 bedded on remnants of 1790 gravel not exceeding an inch in thickness, lying on pre-1790 stony pisolite. Below the 12-inch rule is the pisolitic agglomerate of the fifteenth phreatic eruption. Photograph by H. A. Powers, September, 1947, at locality W.

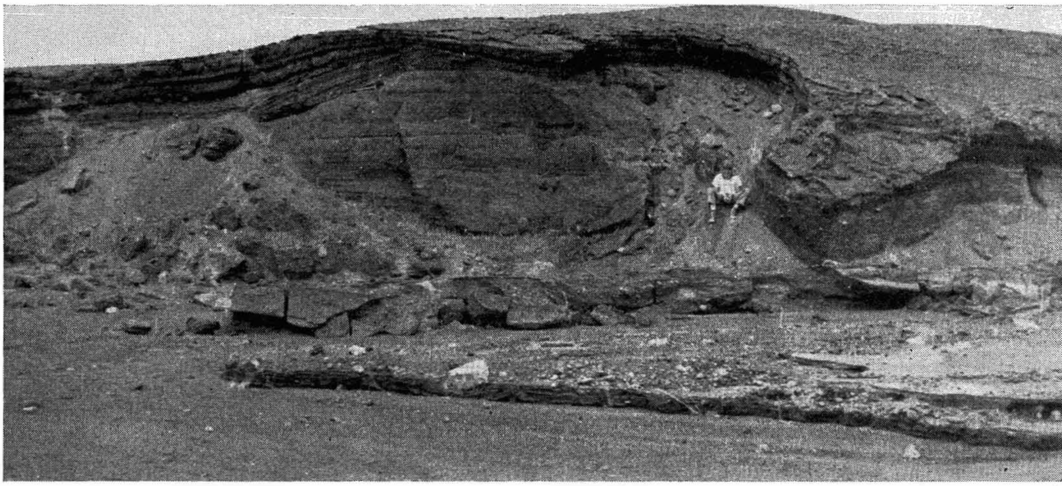

PLATE 4A

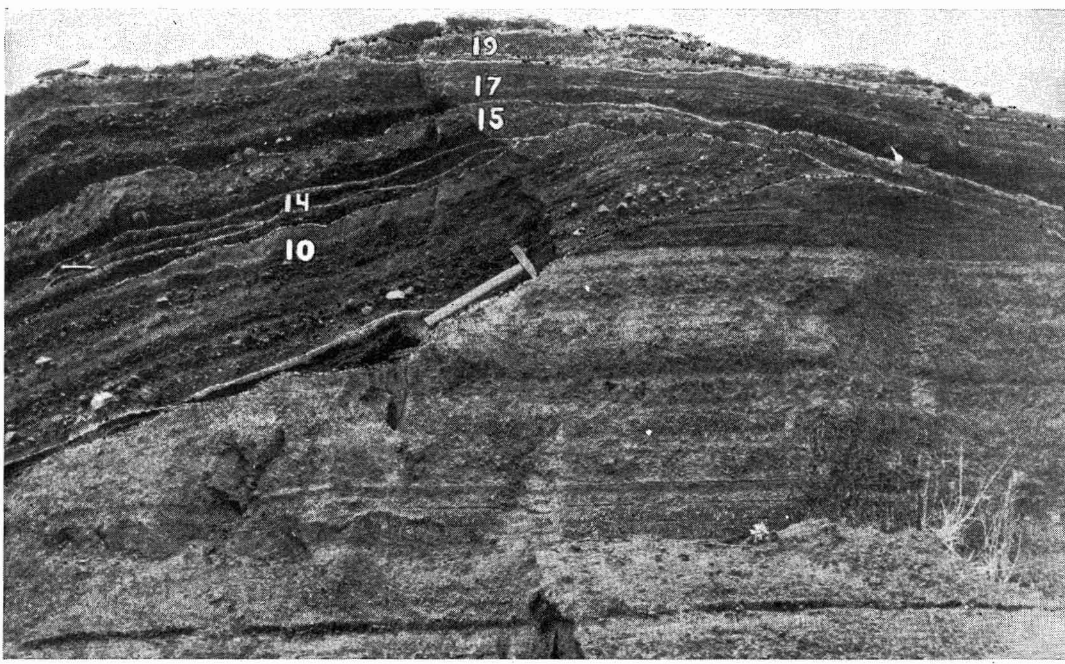

PLATE 4B

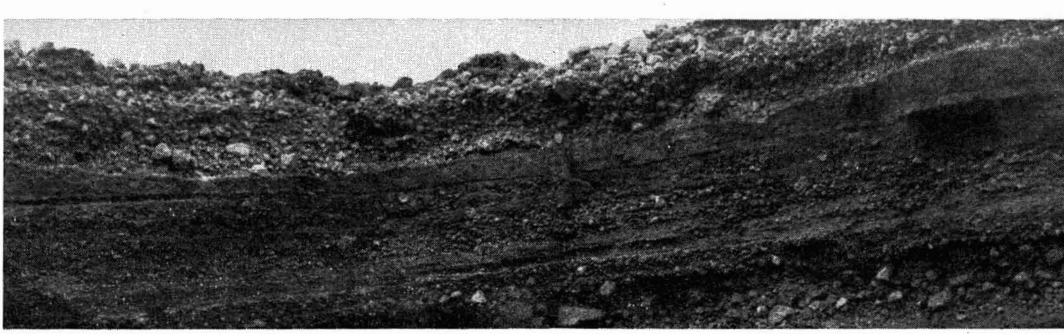

PLATE 4C

ing of at least 26 separate explosive eruptions of Kilauea. Each eruption appears to have been caused either by phreatic or by magmatic explosions; no single eruption seems to require both phreatic and magmatic explosions to account for the lithologic constituents in its deposit.

The Uwekahuna formation seems to have been deposited on the floor and outer slopes of an earlier caldera by at least five magmatic eruptions separated by appreciable time intervals.

The Keanakakoi formation seems to represent at least 10 phreatic and 11 magmatic eruptions which have occurred since the last major overflows of lava which form the present crater rim.

Details of distribution of the Keanakakoi deposits promise to be useful in working out the details of the late structural history of Kilauea. For example, the slumped rim blocks in the northeast corner carry the thickest deposit from eruption number 2-K, suggesting early collapse of these blocks; and most of the deposits on Byron's Ledge are not appreciably thicker than those on the adjacent southeast rim, which is 100 feet higher. Perhaps this indicates a late date for the collapse of Byron's Ledge.

The study of the early Keanakakoi magmatic explosion deposits has a direct bearing on the problem of the contribution of the Kilauea summit crater to the older Pahala ash formation of Hilina Pali and other areas 10 miles or more distant from the summit crater.

The chronological table of explosive eruptions may conceivably be useful as an actual time scale when coupled with results from studies of rate of reforestation. The most mature forest east and north of Kilauea Iki apparently was never killed by any explosive eruption during the Keanakakoi time and thus may represent uninterrupted encroachment from the slope of Mauna Loa as much as 5 miles distant across the surface of the last rim overflow of Kilauea. A less mature forest extending from the crater rim to about a mile northeast of the rim may represent the total development of vegetation since the seventeenth eruption, which probably killed all vegetation to that distance. The growth immediately on the northeast rim may represent the recovery from a partial kill of vegetation in 1790.

The general picture sketched in by this study suggests these long-period fluctuations in the intensity of lava pressure:

(1) pre-Uwekahuna, high-pressure, dome-building phase

(2) low-pressure collapse and explosive eruptions of Uwekahuna tuff

(3) high-pressure, post-Uwekahuna resumption of dome-building

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PLATE 4A. Keanakakoi pyroclastics on the outer slope of the southwest Kilauea rim. Deposits of the fifteenth, seventeenth, eighteenth, and 1790 eruptions mantle an erosion surface which truncates beds of the fourteenth to the tenth eruptions. The erosion surface marked by the hammer truncates the vitric ash of eruptions earlier than the tenth. Details of the section in upper left center show in Plate 4B, and details of the upper beds at the head of the re-entrant behind the figure show in Plate 4C.

PLATE 4B. Remnants of two layers of 1790 gravels, separated by a depositional break, lie on a desert surface truncating the stony pisolite of the eighteenth eruption. Erosion surfaces have been emphasized by retouching on the negative. Beds from the seventeenth eruption reach 8 inches in thickness at the right of the section and lie on the eroded surface of beds from the fifteenth eruption, the lowest layer which is continuous across the face of the section. A lens of pumice from the thirteenth eruption (marked by pocket knife at left) lies between remnant patches of beds from the fourteenth and twelfth eruptions. The vitric deposits from the third and fourth eruptions lie beneath the horizontal desert surface (not retouched), which extends across the photograph just below the grass clump on the right.

PLATE 4C. Gravel of 1790, from 4 to 6 inches thick, lying on the eroded layer of stony pisolitic mud from the eighteenth eruption, originally 3 inches thick in this section. Erosion occurred after consolidation of the pisolitic mud, as it truncates the bedding within the layer, and has cut the bed to a remnant 1 inch thick in the photograph. Beneath the stony pisolite layer is a desert surface eroded on deposits from the seventeenth eruption about 10 inches thick including the basal layer of coarsest fragments.

Photographs by H. A. Powers, September, 1947, at locality U.

(4) low-pressure collapse of present caldera
 (*a*) partial collapse and early Keanakakoi magmatic explosions
 (*b*) severe collapse and phreatic explosions reaching a maximum in the fifteenth and seventeenth eruptions

(5) possible gradual resumption of high-pressure dome-building suggested by the important crater-filling activity since 1790

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